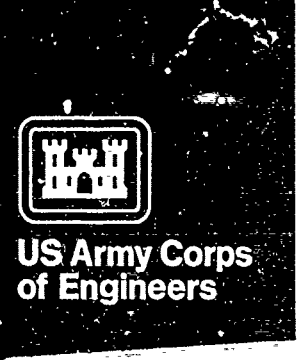

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CHEMICAL MOWING: EFFECT OF PLANT GROWTH RETARDANTS ON PLANT ROOTS

by

O. P. Vadhwa

Department of Agriculture
Alcorn State University
Lorman, Mississippi 39096

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Final Report

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The effects of the plant growth regulators mefluidide and uniconazole on the root growth of Bermudagrass were assessed for 3 years using a traditional rhizotron. Two rhizotron designs were evaluated. The single rhizotron with the viewing glass side inserted at a 45-deg angle proved to be the most efficient and desirable design. The effects of mefluidide and uniconazole were satisfactorily monitored with this technique, and the efficacy of each chemical was determined. The method of application (field- or rhizotron-treated plots) influenced the response of the chemicals; field-treated plugs showed a greater response to mefluidide. The retardation effects of uniconazole were consistent regardless of application method, with the exception of root length, root number, and number of runners in 1990 when treated in the rhizotron. The design of each rhizotron is described and illustrated, and the advantages of such a system are enumerated.

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Preface

Funds for this study were provided by the Headquarters, US Army Corps of Engineers, through the US Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL).

The Principal Investigator for the work was Dr. O. P. Vadhwa, Department of Agriculture, Alcorn State University, Lorman, MS.

The research was monitored at the WES by Dr. Thomas L. Hart and Ms. Linda S. Nelson of the Aquatic Processes and Effects Group (APEG), Ecosystem Research and Simulation Division (ERSD), EL. The study was conducted under the general supervision of Dr. John Harrison, Chief, EL, and Mr. Donald L. Robey, Chief, ERSD, and under the direct supervision of Dr. Thomas L. Hart, Chief, APEG.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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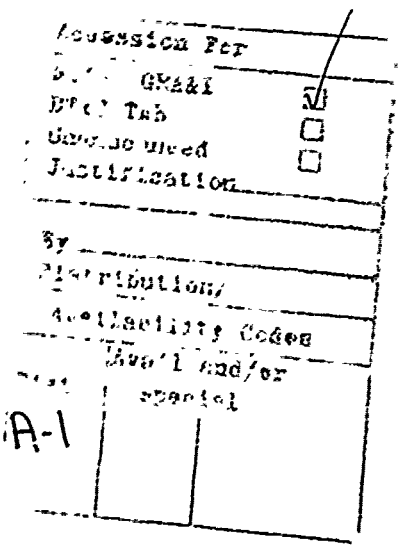

Contents

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
gallons	3.785412	liters
inches	2.54	centimeters
ounces	0.02957353	liters
pounds (mass) per acre	0.000112	kilograms per square meter
square feet	0.09290304	square meters

CHEMICAL MOWING: EFFECT OF PLANT GROWTH RETARDANTS ON PLANT ROOTS

Introduction

Research in the area of plant growth regulators (PGRs) for turf has increased significantly in recent years. PGRs are defined as synthesized inorganic chemical compounds that influence plant growth and development when used in very small amounts. Consequently, PGRs that inhibit turfgrass growth could help to reduce costly frequent mowings.

Studies on chemical growth retardation of turfgrasses have dealt with the effects of PGRs on the aerial parts or the vertical growth of the plant. Minimal research has been conducted on the effect of PGRs on root growth and development. The root system, being the principal water and nutrient absorbing organ, plays an important role in the development of the plant. Therefore, an understanding of root growth dynamics is important. The study of root density and the underground rhizome part of the plant is also important because of their role in recuperative potential of turfgrasses subjected to long-term PGR usage.

Methodologies have been introduced to monitor effects of PGRs on roots. However, most of these techniques are expensive and time consuming. There is a need to develop a simple, efficient method for monitoring the effects of PGRs on root growth and development. The objectives of this study were to develop a methodology for assessing PGR effects on turfgrass root growth and to determine the effects of mefluidide and uniconazole on root growth of Bermudagrass.

Review of Literature

Methods to study plant roots

Bragg, Govi, and Cannell (1983) compared four methods of measuring root distribution: minirhizotrons installed vertically; minirhizotrons installed at an angle of 45 deg;* core-break root counts; and direct measurements of root length from washed soil cores. They concluded that minirhizotrons gave

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

better estimates of root distribution when installed at 45 deg rather than vertically and could be used in the soil horizon between 30 cm below the surface to the maximum depth of rooting. Voorhees (1976) studied root elongation along a soil-plastic container interface and concluded that root elongation rates were significantly lower than those measured with the bulk soil mass method. These differences were probably due either to higher soil strength at the interface or to an attracting electrical charge on the container surface, or both.

Taylor et al. (1970) studied root densities of corn and tomato plants in rhizotrons with transparent panels and concluded that side walls and glass panels showed no concentrating effect on root growth. Taylor and Bohm (1976) reported on the use of acrylic plastic as rhizotron windows and concluded that rooting density was substantially greater in the 2-mm-thick layers near the plastic-soil interface than in the bulk soil behind it. Acrylic plastic windows apparently are satisfactory for use in root growth boxes or rhizotron compartments for phenological and comparative experiments, but glass rhizotron windows should be used in rooting density studies.

Bland and Dugas (1988) used clear plastic tubes buried in the soil (minirhizotrons) to determine root length density. This system, however, is relatively expensive to install. In efforts to minimize cost and simplify measurements, Upchurch and Ritchie (1984) used a battery-operated color video camera for root observations in minirhizotrons. The technique underestimated root length density near the soil surface. Keng (1988) compared the traditional rhizotron with flat-sided viewing panels for root observations to minirhizotrons that used viewing tubes and fiber optical borescope techniques. The viewing tube data were more variable compared with the side-viewing panel. Drew and Saker (1980) evaluated soil cores for estimating the amount and distribution of crop roots in the field. There was a difference in root growth due to field sites. Estimates of root length from observations of soil cores may provide a suitable basis for rapidly comparing the relative distribution of roots down the soil profile under field conditions.

Another method for measuring root growth has been investigated by Ottman and Timm (1984), making use of an image analyzing computer. This technique is relatively rapid and can be used to measure plant root systems using soil cores. Bohm, Maduakor, and Taylor (1977) compared five methods for characterizing soybean rooting density and development. The hard-augered core, soil water depletion, and the trench profile methods could be used through the

entire growing season, but the framed-monolith and the mechanized core methods were not satisfactory during a drought period due to collapse of soil columns. These systems are primarily field techniques.

Muzik and Whitworth (1962) reported the use of a glass-sided box with a light-proof shutter as a technique for periodic observation of root systems in situ. This simple technique permits the detailed study of root growth and development under a variety of experimental conditions. This technique was reported to be useful for root studies related to growth regulation, varietal differences and root development in different soil types, moisture stress, and differing rates and types of fertilization.

Waddington (1971) reported the use of fiber optic equipment for the determination of root penetration, distribution, and density with minimal disturbance to the plant. The method should be useful for investigating root systems in disturbed soil such as greenhouse, growth cabinet, and filled lysimeter experiments.

Taylor (1986) reported several destructive and nondestructive methods to study root systems in the field. The destructive methods included excavations, monoliths, cores, and trench profiles; the nondestructive methods included various modifications of minirhizotrons and rhizotrons. The method selected to study plant roots should be the easiest and simplest that will provide the desired information, such as the nondestructive method using rhizotrons.

Flocker and Timm (1969) studied plant growth and root distribution in layered sand columns in a growth chamber environment. The acrylic plastic columns were satisfactory for examining root distribution of tomato plants. Sanders and Brown (1978) introduced a more expensive and elaborate technique for measuring root growth of soybeans under field conditions. This technique involves the use of a highly refined fiber optic duodenoscope for observing and photographing roots. This method estimated a greater root length than did the soil cores.

Accurate and reliable methods for quantitative studies of roots are essential irrespective of where plants were grown, i.e., minirhizotron or traditional rhizotron. Newman (1966) presented such a method for estimating the total length of roots in a sample. The results indicated that the line intersection method was much quicker than direct measurement of the whole sample. Wilhelm, Norman, and Newell (1983) reported use of a semiautomated

x-y plotter-based method for measuring root lengths. The system used a modified line-intersect technique to estimate root length, and accurately estimated root length of samples up to 10 m in length. The accuracy of the system was comparable to others that were based on the line-intersect technique.

Effects of PGRs on turfgrass roots

Fales, Nielsen, and Wakefield (1976) studied the effect of four growth retardants on top growth and root growth of red fescue and concluded that all materials tested reduced top growth, seedhead production, and seedhead height; caused discoloration; and reduced turf density. Results indicated that treatments of Sustar, maleic hydrazide and maleic hydrazide + chlorflurenol caused a reduction in the growth of new roots. VEL 3793 caused virtually no suppression of root growth while maintaining significantly reduced top growth (Fales, Nielsen, and Wakefield 1976). Similar work had been reported by Nielsen and Wakefield (1975) on a highway turf mixture; they concluded that treatment with the growth regulant mefluidide resulted in less suppression of root growth than other treatments and that rhizomes and seedheads were also suppressed by all growth retardants.

Wakefield and Dore (1974) tested growth retardants on highway turf to evaluate the response of Kentucky bluegrass, red fescue, and Colonial bentgrass to applications of maleic hydrazide, chlorflurenol, a combination of maleic hydrazide and chlorflurenol, and Sustar. All retardants significantly reduced vegetative and seedhead growth. Root growth was also significantly inhibited by all materials.

Wakefield and Fales (1980) also evaluated growth retardants (fluoridimide and mefluidide) to determine their effects on shoot and root growth of several turfgrass species under roadside conditions. Root growth, as measured by root weights from treated turfgrass plugs, was initially reduced by all growth retardants. Reduction in root growth with mefluidide was far less severe, recovery was rapid, and some stimulation of root growth was measured following initial chemical inhibition. Rhizome growth of Kentucky bluegrass was also less affected with mefluidide than with the other growth retardants.

Christians and Nau (1984) reported the effects of three growth retardants on three turf species, including Kentucky bluegrass. Ethephon at 2.24 kg/ha reduced Kentucky bluegrass clipping weight and increased root and rhizome development. Christians (1985) studied the response of Kentucky bluegrass to four growth retardants and concluded that none of the growth

retardants inhibited root organic matter production or rhizome weight. McCarty et al. (1985) concluded that spring-applied plant growth retardant treatments did not reduce root dry weight during a 2-year study.

Campbell (1986) compared several plant growth regulators and concluded that flurprimidol and paclobutrazol applications increased the root:shoot ratios of Kentucky bluegrass and perennial ryegrass. Kaufmann et al. (1983) examined MON-4620, an experimental turfgrass growth retardant, and concluded that continued growth and enhancement of roots of treated plants was a result of compensation due to crown inhibition.

Dernoeden (1983, 1984) evaluated the effects of PGRs applied twice annually for four consecutive years on a Kentucky bluegrass-red fescue turf and concluded that there were no deleterious effects of PGR usage on tiller and root recuperative potential. Significantly higher root weights were associated with flurprimidol G (2.2 and 3.4 kg/ha) treatments. Root weight was positively correlated with tiller number, indicating that flurprimidol G increased tiller number.

Elkins, Vandeventer, and Briskovich (1977) conducted a greenhouse experiment to determine the influence of 19 growth retardant treatments on several morphological growth parameters of tall fescue and Kentucky bluegrass. Most of the treatments that caused aerial growth reduction also restricted root spread, volume, and dry weight. Some retardants also reduced tall fescue and Kentucky bluegrass tiller number and bluegrass rhizome development.

Schmidt and Bingham (1977) concluded that all growth regulators and formulations evaluated caused some phytotoxicity to foliage, especially at higher dosages. All growth regulators except metolachlor reduced root growth a year following application. Fluridamid and mefluidide suppressed rooting the most. Roots were suppressed by all growth regulators applied the second year. Growth regulators affected root growth for a longer period of time than they affected the foliage. Dernoeden (1986) reported that the use of plant growth regulators such as chlorflurenol, fluridamid, maleic hydrazide, and mefluidide at recommended rates inhibited rooting of bluegrass turf grown in sand culture.

Youngner and Nudge (1974) studied the effect of three growth retardants on various grass tissues and organs including roots tillers, rhizomes, stolons, and reserve carbohydrates. The growth retardant 2-chloroethyl trimethylammonium slightly retarded bermudagrass root growth, but did not affect root growth of Kentucky bluegrass unless high rates were used. High rates of

Acymidol also inhibited root growth of Kentucky bluegrass. Fluridamid did not stimulate either tillering or rhizome development. Nelson, Dunn, and Coutts (1977) reported that the use of ancymidol reduced root growth of Bermudagrass but not of tall fescue.

Temmen and Elkins (1984) evaluated the effects of several growth regulators on root initiation and growth, and on tiller and rhizome development. The growth regulator treatments that reduced top growth also significantly inhibited root initiation and growth. These results may have significant implications for maintaining dense, long-term turfgrass stands after using certain plant growth regulators.

White et al. (1969) concluded that ethrel treatments on Kentucky bluegrass resulted in growth retardation of both roots and shoots for a limited period of time. Increased tillering and leaf number were noted after growth resumed. Parups and Cordukes (1977) applied Atrinal and mefluidide to turfgrasses and concluded that Atrinal retarded the growth of turfgrasses grown in the greenhouse but not in the field. Mefluidide inhibited field-grown turf early in the season only.

Cooper et al. (1984) studied the effects of two rates of mefluidide on annual bluegrass quality and rooting. Rooting behavior did not vary among treatments during most of the growing season. However, following mid-July heat stress, mefluidide-treated turf exhibited a greater root elongation rate and rooting depth than the control for a 4- to 5-week period. Cooper et al. (1987) indicated that root elongation of mefluidide-treated annual bluegrass was superior to the untreated controls for 2 to 4 weeks following treatment. Maximum rooting depth of mefluidide-treated turf was also significantly greater than that of Aqua-Gro-treated or untreated turf. Aqua-Gro did not show promise as an inhibitor of annual bluegrass seedheads and had little effect on rooting.

Bhowmik (1987) studied the response of red fescue and Kentucky bluegrass turf to three consecutive annual applications of amidochlor, mefluidide, and ethephon and concluded that root length, root weight, and root.shoot ratio of sampled turf plugs from the greenhouse study were unaffected by all chemicals.

Brown and White (1974) concluded that growth regulators reduced root growth of a Kentucky bluegrass sod transplanted 3 months after treatment. Turf treated with growth regulators and supplemental potassium produced twice the root growth compared to grass treated with growth regulators alone.

Wu and Harivandi (1988) evaluated the use of paclobutrazol on four Bermudugrass cultivars, including common Bermudagrass, and concluded that paclobutrazol caused a 20-percent reduction in stolon length and number of internodes but root weight was not affected.

McCarty, Miller, and Colvin (1990) conducted a 2-year greenhouse study to evaluate the root growth response of 'Kentucky 31' tall fescue to treatments of mefluidide and flurprimidol. No root-growth inhibition was observed during the experiment.

Eggens, Wright, and Carey (1989) evaluated the effect of mefluidide on the growth of annual bluegrass under pot culture and field conditions. In pot culture, mefluidide caused a significant reduction in shoot and root dry weight and tiller number of single, annual bluegrass plants and of annual bluegrass planted at high densities. Root responses to mefluidide under field conditions were not evaluated.

Effects of PGRs on
carbohydrate reserves of roots

Cooper (1985) showed that seedhead suppression associated with mefluidide application resulted in increased fructose and glucose in annual bluegrass roots and that mefluidide treatment had little effect on leaf and stem carbohydrates. Regardless of mefluidide rate, concentrations of fructose, sucrose, and fructans were considerably greater in leaf and stem tissue than in roots. Annual bluegrass stems were the major storage organ for fructans, with only minor fructan storage occurring in roots. The carbohydrate content of mefluidide-treated annual bluegrass decreased substantially in leaf, stem, and root tissue following growth inhibition due to a postinhibition growth surge.

Hanson and Branham (1987) studied the photosynthate partitioning patterns in 'Majestic' Kentucky bluegrass as influenced by various PGRs. Amidochlor and mefluidide caused an increase in photosynthate accumulation in the crown, whereas treatment with paclobutrazol and flurprimidol caused a decline in photosynthate partitioning to the roots. Youngner and Nudge (1974) showed that nonstructural carbohydrate percentages of roots and crowns of Bermudagrass were not affected by CCC (2-chloroethyl trimethylammonium).

Effect of PGRs on the
establishment of turf sod

Procedures utilizing PGRs to hasten vegetative establishment would be useful to the turfgrass industry. One possibility is the use of growth

retardants to selectively retard growth of competing species. Hubbell and Dunn (1985) showed that growth retardants in combination with certain N fertilization techniques can enhance the spread of transplanted zoysiagrass without serious injury to the existing bluegrass sward. In addition, growth regulators and organic compounds such as binetin, the fungicide bayleton, and certain herbicides showed promise as root-enhancing agents and may also influence rooting of grass sod, as indicated by Beard (1986).

Materials and Methods

Experiment I
(October 1988-December 1988)

Turf plugs of common Bermudagrass (*Cynodon dactylon*), acquired from an established lawn at Alcorn State University, were used in this study. The turf area was mowed to a uniform height before taking turf plugs for transplanting into wooden boxes. The plugs were 2 in. in diameter and 2 in. long. Turf plugs were prepared for transplantation by pruning the roots to equal lengths. Plugs were transplanted into wooden rhizotrons 24 in. by 4 in. by 24 in. with a viewing glass side (Figure 1). Each rhizotron was partitioned

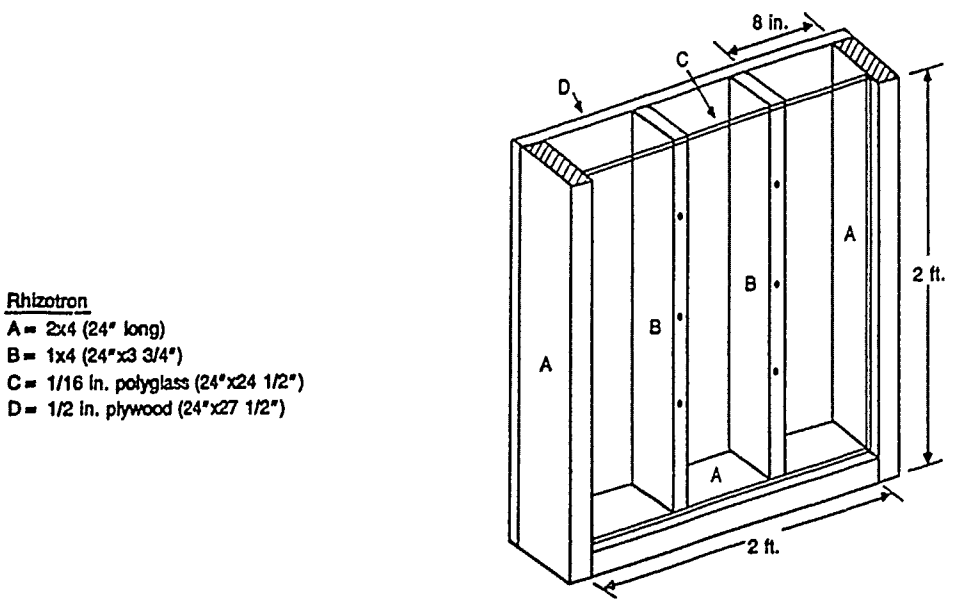


Figure 1. Labeled diagram illustrating rhizotron

into three equal parts. Each partition contained a Bermudagrass turf plug that received a given concentration of a selected plant growth regulator. The rhizotrons were placed at a 45-deg angle with the viewing glass side down, as described by Bragg, Gori, and Cannell (1983).

The plugs were allowed to establish for approximately 3 weeks, or until adequate root growth was noted through the viewing glass. At this time, the PGRs were applied, and the monitoring of various root growth parameters began.

The growing medium used was sterilized sand and vermiculite (2:1 by volume). A soluble fertilizer, 20-20-20 plus a minor nutrient mix, was used to maintain healthy growing plugs. The plugs were fertilized with this solution once a week. Plants were watered as often as needed to maintain them in a healthy condition. The same amount of water was applied to each compartment of each wooden rhizotron. Two holes were drilled at the base of each compartment to provide drainage of excessive water.

Shoot growth of all turf plugs was trimmed to a uniform height before PGR treatment. The plant growth regulators mefluidide and uniconazole were foliar applied at six concentrations (0, 1/2X, X, 2X, 3X, and 4X). The X concentration for mefluidide and for uniconazole was equal to the manufacturer's recommended label rate for Bermudagrass. Foliar application of each PGR treatment was made to individual plugs in each compartment using a small hand sprayer. Separate sprayers were used for each concentration of PGR to avoid contamination. Control plugs were sprayed with tap water only. The rhizotrons plugs were maintained in the greenhouse.

Treatment effects on root growth were monitored by taking root measurements as viewed through the glass side of the rhizotron. Root length was measured weekly using a metric ruler. At the end of the experiment, data were also collected on the number of roots for each treatment and fresh weights of shoots and roots.

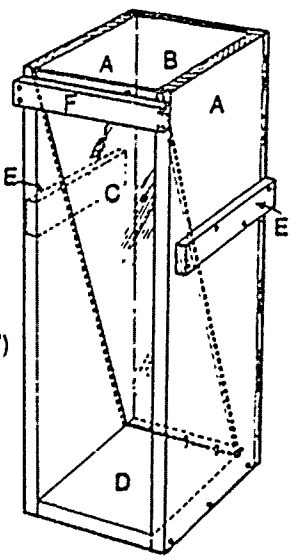
The experiment was a 2 × 6 factorial utilizing two growth regulators at six concentrations. Treatments were arranged in a randomized complete block design with four replicates. A single turf plug represented one replication. The data collected were subjected to analysis of variance and linear or nonlinear regression; treatment means were separated by the Duncan's Multiple Range Test.

Experiment II
(September 1989-January 1990)

Experiment II was conducted using a slightly modified method previously described in experiment I. Rhizotrons were modified to facilitate data collection and consisted of three wooden sides and a viewing glass side in which the glass was inserted at a 45-deg angle (Figure 2). To avoid contamination from adjacent treatments, this rhizotron was not partitioned like the one used in experiment I. One turf plug was transplanted in each rhizotron.

Treatments were applied to transplanted turf plugs using previously described procedures. In addition, a separate study was conducted in which PGR treatments were applied to established Bermudagrass turf plots in the field. All treatments were applied to the point of drip with a 3-gal backpack Solo sprayer. Fourteen days after treatment application, turf plugs were collected from treated field plots and transplanted to rhizotrons. The plant growth regulators uniconazole and mefluidide were foliar applied at five concentrations (0, 1/2, X, 2X, and 4X). The X concentration was equal to the manufacturer's recommended label rate for Bermudagrass. Parameters measured included those previously stated in experiment I, with the addition of dry weights of roots, shoots, and crowns; number of runners; and final plant height.

The number of replications was increased from four to five to reduce experimental variability. The experimental design and method of data analysis were the same as in experiment I.



Rhizotron
A = 3/4"x10 3/4"x24"
B = 1/2 in. plywood (8 1/2"x24")
C = 1/8 in. polyglass (7 1/2"x25")
D = 3/4"x7"x10 3/4"
E = 5/8"x1 3/8"x10 1/2"
F = 5/8"x1 3/8"x8 1/2"

Figure 2. Diagram of rhizotron

Experiment III
(June 1990-October 1990)

This experiment was conducted in the same manner as experiment II, with the exception of timing of application. All turf plugs were collected and transplanted in late May. PGR treatments were applied 2 weeks after transplanting, to monitor the effects of PGRs on root growth during June through October 1990 (the most active growth period of Bermudagrass). Plants were kept outside under natural conditions. To provide protection from inclement weather, a canopy was built from corrugated fiberglass supported by a wooden frame. The experimental design and method of data analysis were the same as in experiment II.

Results

Experiment I
(October 1988-December 1988)

Mefluidide significantly reduced the fresh weight of Bermudagrass roots as compared to the control. All rates of mefluidide were equally effective. Mefluidide did not influence any of the remaining growth parameters (Table 1). All concentrations of uniconazole were equally effective in significantly reducing shoot and root fresh weights of Bermudagrass as compared to the control (Table 2). Numbers of roots, however, were reduced only by the higher rates of uniconazole (2, 4, 6, and 8 lb active ingredient (a.i.)/acre). Root length was reduced only by the higher rates of 4, 6, and 8 lb a.i./acre of uniconazole. Plant height was reduced by all rates of uniconazole. The greatest reduction occurred with rates of 2, 4, 6, and 8 lb a.i./acre, which were equally effective in reducing plant height.

Experiment II
(September 1989-January 1990)

Field-treated turf plugs. Mefluidide did not influence shoot or crown fresh and dry weights or root dry weight. Root fresh weights were reduced by mefluidide at 3 oz/1,000 ft^2 (Table 3). Root length was not influenced by mefluidide. Root number was reduced by mefluidide at 3 oz/1,000 ft^2. The number of runners was not influenced as compared to the control; however, mefluidide at 1.5 oz/1,000 ft^2 decreased the number of runners when compared to the remaining mefluidide treatments. Total plant height was not affected by mefluidide (Table 4).

Table 1

Effects of Mefluidide on Growth Parameters of Bermudagrass, October 1988-December 1988

Mefluidide oz/1,000 ft^2 (ml/305 m^2)	Shoot Fresh Wt. (g)	Root Fresh Wt. (g)	Number of Roots	Root Length (cm)	Plant Height (cm)
0 (Control)	1.2a*	8.2a	9.5a	31.5a	15.0a
0.75 (22)	1.2a	5.6b	10.5a	37.0a	13.5a
1.5 (44.3)	1.0a	4.6b	8.0a	35.7a	12.7a
3.0 (88.5)	1.0a	3.7b	9.5a	47.7a	12.5a
4.5 (132.8)	0.9a	5.3b	9.5a	38.0a	13.2a
6.0 (177.0)	1.2a	3.4b	10.7a	31.0a	11.7a

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 2

Effects of Uniconazole on Growth Parameters of Bermudagrass, October 1988-December 1988

Uniconazole lb a.i./acre (kg/ha)	Shoot Fresh Wt. (g)	Root Fresh Wt. (g)	Number of Roots	Root Length (cm)	Plant Height (cm)
0	1.2a*	8.2a	9.5a	31.5a	15.0a
1(1.1)	0.6b	3.7b	6.5a	21.7a	5.0b
2(2.3)	0.5b	2.1b	3.5b	23.0a	3.3c
4(4.5)	0.7b	3.2b	4.5b	12.8b	3.0c
6(6.7)	0.4b	2.8b	4.7b	13.5b	3.3c
8(9.0)	0.3b	2.2b	3.2b	14.5b	2.5c

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 3

Influence of Mefluidide on Bermudagrass

Field-Treated Turf Plugs, 1989

Mefluidide oz/1,000 ft^2	Root Weight (g)		Shoot Weight (g)		Crown Weight (g)	
	Fresh	Dry	Fresh	Dry	Fresh	Dry
0	5.8a*	1.5ab	3.6a	1.3a	9.0a	3.1a
0.75	4.2ab	1.7ab	2.5a	1.1a	10.8a	3.9a
1.50	5.0a	2.1a	3.4a	1.5a	8.2a	4.1a
3.00	2.3b	1.0b	2.7a	1.2a	9.0a	3.0a
6.0	4.7a	1.3ab	3.8a	1.7a	7.4a	2.9a

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 4

Influence of Mefluidide on Bermudagrass

Field-Treated Turf Plugs, 1989

Mefluidide oz/1,000 ft^2	Root		No. Runners	Total Plant Weight (cm)
	Length (cm)	Number		
0	110.4ab*	62.0ab	6.4ab	11.2a
0.75	44.4ab	42.2bc	7.0a	11.5a
1.50	49.4ab	49.0abc	4.2bc	12.7a
3.00	38.0b	25.4c	7.0a	10.8a
6.0	159.6a	76.0a	7.0a	13.1a

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Uniconazole reduced root fresh weight at 2, 4, and 8 lb a.i./acre. Root dry weight was reduced only by the highest concentration of uniconazole (8 lb a.i./acre). Shoot fresh weight was reduced by uniconazole, but there was no significant difference among uniconazole treatments. Uniconazole at 4 lb a.i./acre reduced crown fresh weights. Crown dry weight was not affected (Table 5). Root length was not influenced by uniconazole [illegible] pared to the control. However, uniconazole at 1 lb a.i./acre increased root length as compared to uniconazole at 8 lb a.i./acre. Root number and [illegible] height were reduced by uniconazole, but there were no significant differences among uniconazole treatments. The number of runners was reduced by treatments of 4 and 8 lb a.i./acre of uniconazole (Table 6).

Rhizotron-treated turf plugs. Mefluidide reduced root fresh and dry weights only at the highest rate (6 oz/1,000 ft^2). Shoot and crown weights were not affected by mefluidide (Table 7). Root length, number of roots, number of runners, and total plant height also were not affected by mefluidide (Table 8).

Uniconazole significantly reduced root and shoot weights compared to the untreated control; however, there were no significant differences among uniconazole concentrations. Crown fresh weight was reduced by 2, 4, and 8 lb a.i./acre. Crown dry weight was not affected by uniconazole (Table 9). Root length was reduced by uniconazole at 4 lb a.i./acre. The number of roots, number of runners, and total plant height were reduced by all treatments of uniconazole; however, there were no significant differences among treatment concentrations (Table 10).

Experiment III
(June 1990-October 1990)

Field-treated turf plugs. Mefluidide did not influence root, shoot, or crown weights (Table 11). Root length and root number were reduced by mefluidide at 6 oz/1,000 ft^2. Mefluidide did not influence the number of runners or total plant height as compared to the control (Table 12).

Uniconazole reduced root fresh and dry weights of roots. Fresh weight was reduced by 2, 4, and 8 lb a.i./acre uniconazole. All uniconazole concentrations were equally effective in reducing root dry weight. Shoot fresh weights were reduced by 2, 4, and 8 lb a.i./acre of uniconazole; however, shoot dry weight was reduced by uniconazole only at 4 lb a.i./acre. Crown fresh and dry weights were not influenced by uniconazole (Table 13). Uniconazole at 4 and 8 lb a.i./acre reduced root length and number of runners.

Table 5

Influence of Uniconazole on Bermudagrass

Field-Treated Turf Plugs, 1989

Uniconazole lb a.i./acre	Root Weight (g) Fresh	Root Weight (g) Dry	Shoot Weight (g) Fresh	Shoot Weight (g) Dry	Crown Weight (g) Fresh	Crown Weight (g) Dry
0	3.5a*	1.43a	3.6a	1.6b	8.4a	2.6a
1	2.8a	0.78ab	2.1b	0.8b	7.1ab	2.0a
2	1.0b	0.50ab	1.9b	0.9b	6.0ab	2.2a
4	1.2b	0.84ab	1.6b	0.5b	4.2b	1.7a
8	0.2b	0.09b	1.3b	0.6b	6.9ab	3.1a

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 6

Influence of Uniconazole on Bermudagrass

Field-Treated Turf Plugs, 1989

Uniconazole lb a.i./acre	Root Length (cm)	Root Number	No. Runners	Total Plant Height (cm)
0	72.9ab*	70.0a	6.8a	10.7a
1	93.3a	27.0b	4.2ab	6.7b
2	23.9b	18.2b	4.4ab	5.9b
4	43.4ab	19.8b	2.0bc	6.1b
8	11.0b	14.4b	1.2c	5.8b

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 7

Influence of Mefluidide on Bermudagrass

Rhizotron-Treated Turf Plugs, 1989

Mefluidide oz/1,000 ft^2	Root Weight (g)		Shoot Weight (g)		Crown Weight (g)	
	Fresh	Dry	Fresh	Dry	Fresh	Dry
0	7.5a*	2.5a	5.4a	2.4a	11.2a	3.7a
0.75	6.5a	1.9a	3.7a	1.6a	8.9a	3.8a
1.5	5.6a	2.4a	4.5a	2.2a	8.9a	4.0a
3.0	5.7a	2.2a	4.0a	1.9a	9.9a	3.4a
6.0	3.1b	0.8b	4.6a	2.1a	8.9a	2.9a

* Means in columns separated by Duncan Multiple Range Test, 5-percent level.

Table 8

Influence of Mefluidide on Bermudagrass

Rhizotron-Treated Turf Plugs, 1989

Mefluidide oz/1,000 ft^2	Root		No. Runners	Total Plant Height (cm)
	Length (cm)	Number		
0	70.5a*	55.0a	8.2ab	11.3a
0.75	100.7a	48.4a	9.2a	11.2a
1.50	63.3a	55.0a	7.0ab	10.7a
3.0	75.7a	47.0a	7.4ab	12.1a
6.0	44.8a	31.6a	5.4b	12.5a

* Means in columns separated by Duncan Multiple Range Test, 5-percent level.

Table 9

Influence of Uniconazole on Bermudagrass

Rhizotron-Treated Turf Plugs, 1989

Uniconazole	Root Weight (g)		Shoot Weight (g)		Crown Weight (g)	
lb a.i./acre	Fresh	Dry	Fresh	Dry	Fresh	Dry
0	7.5*	4.0a	6.3a	2.8a	11.8a	4.1a
1	2.3b	0.8b	2.7b	0.9b	9.6ab	2.8a
2	1.0b	0.4b	2.2b	0.9b	7.2b	2.3a
4	1.2b	0.4b	1.4b	0.5b	7.1b	3.3a
8	1.6b	0.8b	1.2b	0.5b	5.9b	2.1a

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 10

Influence of Uniconazole on Bermudagrass

Rhizotron-Treated Turf Plugs, 1989

Uniconazole	Root		No.	Total Plant
lb a.i./acre	Length (cm)	Number	Runners	Height (cm)
0	53.5ab*	78.0a	9.4a	12.7a
1	59.7a	21.0b	3.4b	6.4b
2	37.9abc	12.6b	3.2b	6.3b
4	22.2c	16.6b	3.0b	6.1b
8	25.3bc	15.8b	3.4b	6.0b

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 11

Influence of Mefluidide on Bermudagrass

Field-Treated Turf Plugs, 1990

Mefluidide oz/1,000 ft^2	Root Weight (g)		Shoot Weight (g)		Crown Weight (g)	
	Fresh	Dry	Fresh	Dry	Fresh	Dry
0	6.7a*	1.5a	3.1a	1.6a	7.4a	2.7a
0.75	5.9a	1.6a	3.8a	1.9a	7.0a	3.0a
1.50	5.6a	1.5a	3.4a	2.0a	7.0a	2.8a
3.00	5.9a	1.6a	4.3a	2.2a	9.0a	3.2a
6.0	4.5a	1.1a	3.3a	1.7a	7.7a	2.8a

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 12

Influence of Mefluidide on Bermudagrass

Field-Treated Turf Plugs, 1990

Mefluidide oz/1,000 ft^2	Root		No. Runners	Total Plant Height (cm)
	Length (cm)	Number		
0	541.4a*	33.8a	2.8ab	17.4ab
0.75	520.9a	33.0a	4.0a	18.1ab
1.50	379.7ab	30.0ab	1.6b	14.4b
3.00	375.4ab	28.8ab	3.2a	21.1a
6.0	237.1b	20.4b	1.8b	16.9ab

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 13

Influence of Uniconazole on Bermudagrass Field-Treated Turf Plugs, 1990

Uniconazole lb a.i./acre	Root Weight (g) Fresh	Root Weight (g) Dry	Shoot Weight (g) Fresh	Shoot Weight (g) Dry	Crown Weight (g) Fresh	Crown Weight (g) Dry
0	6.7a*	1.88a	4.2a	2.1a	7.4a	2.8a
1	4.5a	0.82b	3.5ab	1.8ab	7.4a	2.5a
2	1.2b	0.46b	2.2b	1.2ab	3.7a	1.3a
4	0.8b	0.24b	1.6b	0.9b	6.3a	2.1a
8	0.3b	0.09b	1.9b	1.2ab	5.0a	1.4a

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Root number was reduced by uniconazole at 2, 4, and 8 lb a.i./acre. Total plant height was reduced by all concentrations of uniconazole, with 8 lb a.i./acre being most effective (Table 14).

Rhizotron-treated turf plugs. Mefluidide did not influence root fresh or dry weights. Shoot and crown fresh and dry weights were increased by mefluidide at 0.75 oz/1,000 ft^2 but were not affected by any other mefluidide treatments (Table 15). Mefluidide did not influence root length, number of roots, number of runners, or total plant height (Table 16).

All treatments of uniconazole reduced root and shoot fresh and dry weights compared to the untreated control; however, there were no significant differences among uniconazole concentrations. Crown fresh weight was reduced only by 8 lb a.i./acre uniconazole, and crown dry weight was reduced by 4 and 8 lb a.i./acre uniconazole (Table 17). Root length, number of roots, and number of runners were not influenced by uniconazole. Total plant height was reduced by uniconazole, but there was no significant difference among uniconazole treatments (Table 18).

Discussion

Mefluidide reduced root fresh weight in two out of three experiments when grown in the rhizotron. Root dry weight was reduced by mefluidide in only one experiment. These findings are consistent with Wakefield and Fales

Table 14

Influence of Uniconazole on Bermudagrass

Field-Treated Turf Plugs, 1990

Uniconazole lb a.i./acre	Root Length (cm)	Root Number	No. Runners	Total Plant Height (cm)
0	415.9a*	31.4a	2.8a	20.4a
1	322.0ab	24.4ab	2.4a	13.4b
2	221.7abc	15.8bc	1.6ab	8.7bc
4	127.2bc	14.6bc	1.0b	9.3bc
8	35.1c	5.0c	0.6b	7.1c

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 15

Influence of Mefluidide on Bermudagrass

Rhizotron-Treated Turf Plugs, 1990

Mefluidide oz/1,000 ft^2	Root Weight (g) Fresh	Root Weight (g) Dry	Shoot Weight (g) Fresh	Shoot Weight (g) Dry	Crown Weight (g) Fresh	Crown Weight (g) Dry
0	5.9a*	1.4a	2.3b	1.7b	7.6b	2.4b
0.75	7.6a	1.9a	6.3a	3.2a	12.5a	4.2a
1.50	5.4a	1.8a	4.4ab	2.5ab	7.6b	2.3b
3.00	5.2a	1.3a	4.1ab	2.0b	7.2b	2.4b
6.0	4.4a	1.2a	3.1b	1.5b	6.6b	2.0b

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 16

Influence of Mefluidide on Bermudagrass

Rhizotron-Treated Turf Plugs, 1990

Mefluidide oz/1,000 ft^2	Root Length (cm)	Root Number	No. Runners	Total Plant Height (cm)
0	412.7a*	31.6a	4.0ab	21.0ab
0.75	450.3a	30.8a	5.2a	24.5a
1.50	422.5a	31.2a	3.2b	22.7a
3.00	380.7a	27.4a	4.4ab	19.7ab
6.0	326.2a	24.0a	3.2b	14.1b

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 17

Influence of Uniconazole on Bermudagrass

Rhizotron-Treated Turf Plugs, 1990

Uniconazole lb a.i./acre	Root Weight (g) Fresh	Root Weight (g) Dry	Shoot Weight (g) Fresh	Shoot Weight (g) Dry	Crown Weight (g) Fresh	Crown Weight (g) Dry
0	8.8a*	1.8a	4.7a	2.5a	9.7a	3.1a
1	3.2b	0.7b	2.1b	1.0b	8.1ab	2.3ab
2	3.1b	0.8b	1.8b	0.6b	8.3ab	2.6ab
4	2.2b	0.5b	1.4b	0.7b	7.2ab	1.9b
8	2.4b	0.5b	1.7b	1.0b	6.2b	1.9b

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

Table 18

Influence of Uniconazole on Bermudagrass Rhizotron-Treated Turf Plugs, 1990

Uniconazole lb a.i./acre	Root Length (cm)	Root Number	No. Runners	Total Plant Height (cm)
0	371.5a*	30.2a	3.2a	21.9a
1	308.0a	29.2a	2.4a	11.3b
2	323.2a	30.6a	2.2a	10.9b
4	221.3a	21.4a	2.4a	10.8b
8	253.5a	21.4a	2.2a	13.3b

* Means in columns with the same letter do not differ according to Duncan's Multiple Range Test, 5-percent level.

(1980), who reporte that mefluidide reduced root weights of several turf species under roadside conditions. Mefluidide increased shoot and crown weights in 1990 but not in 1989. This yearly variation in response may be due to climatic conditions, since in 1989 the rhizotrons were kept in the greenhouse and in 1990 the rhizotrons were outside under protective covering. In pot culture, mefluidide was reported to cause a significant reduction in shoot and root dry weight of annual bluegrass (Eggens, Wright, and Carey 1989).

In all experiments, root length, root number, number of runners, and final plant height was not influenced by mefluidide. Such findings contradict studies by Nielsen and Wakefield (1975), who observed that suppression of root growth on highway turf was significant. Wakefield and Fales (1980) reported, however, that reductions in root growth of turf treated with mefluidide were less severe than with other growth retardants tested. In another experiment, mefluidide was found to suppress rooting the most (Schmidt and Bingham 1977).

Mefluidide on field-treated turf plugs was found to reduce root length and root number. Such reduction was not observed on rhizotron-treated plugs. Apparently turf treated in the field has a greater affinity for mefluidide, possibly due the undisturbed nature of the turf. The retardation effects of mefluidide in this case (field-treated) are consistent with other researchers (Nielsen and Wakefield 1975; Schmidt and Bingham 1977; Wakefield and Fales 1980; Eggens, Wright, and Carey 1989). In field-treated plugs, as in rhizotron-treated plots, mefluidide did not affect plant height or runner number.

In all three experiments, uniconazole has a retarding effect on all growth parameters. However, in 1990 when turf plugs were grown in the rhizotron under a protective shelter, root length, root number, and number of runners were not affected. In addition, crown dry weights were not affected in 1989 when the plugs were grown in the greenhouse. In general, the inhibitory effects of uniconazole are consistent with the literature (Matta, Vadhwa, and Chong 1988; Ammon, Griffin, and Tate 1989; Newman, Tenney, and Follet 1989).

Conclusion

The traditional rhizotron method was identified as a very efficient and inexpensive method for monitoring the effects of PGRs on root growth. The advantages of such a system are as follows:

a. Inexpensive.

b. Contains a glass viewing side that allows monitoring of root growth and number; thus, very efficient.

c. Nondestructive method for root studies.

d. Simple and easy to construct.

e. Various soil media can be used.

f. Size adjustment is possible to regulate soil volume.

g. Portable and easy to handle.

In addition, two rhizotron designs were evaluated. The single rhizotron with the viewing glass side inserted at a 45-deg angle (Figure 2) proved to be the most efficient and desirable design. No contamination during application occurred with this design, and the container did not need to be tilted to produce a 45-deg angle. Thus, the design was more efficient and easier to handle.

The effects of mefluidide and uniconazole were satisfactorily monitored with this technique. The method of application (field- or rhizotron-treated plots) appeared to influence the response of the chemicals. For example, field-treated plugs responded more to mefluidide than rhizotron-treated plugs. Uniconazole effects were consistent regardless of treatment method with the exception of root length, root number, and number of runners in 1990 when treated in the rhizotron. It seems that treating established turf results in a more efficient uptake of the chemical by the plants.

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